BROOKHAVEN NATIONAL LABORATORY

ENVIRONMENTAL, SAFETY, AND HEALTH STANDARD

DESIGN CRITERIA FOR ELECTRICAL EQUIPMENT	*1.5.2*

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Approved by: [signature]
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I. INTRODUCTION

The recognition of the hazards associated with the many types of electrical equipment used in research and development (R&D) and in the support of these activities is of paramount importance to a successful electrical safety program. Once these hazards are clearly recognized, they can be eliminated or minimized.

II. SCOPE

General design criteria for a variety of the basic types of electrical equipment used in R&D are discussed here. A brief description of the particular equipment, a listing of the types of known hazards, the design, construction, and operational criteria are given. The intent of this Standard is not to supersede existing codes and standards, but to supplement them in unique R&D applications. This Standard is not intended to be retroactive for existing applications, but should be used in new designs and retrofitting, however when practical and cost effective, existing facilities should be upgraded.

III. RESPONSIBILITIES

A. ***Department Chairs/Division Heads*** are responsible for ensuring the implementation of this Standard by requiring that equipment is designed, constructed, installed, operated, and maintained in conformance according to this Standard.

B. Line Supervisors are responsible for directly implementating this Standard. They shall:

1. Ensure that all equipment is designed, constructed, installed, operated, and maintained in conformance with all applicable safety codes and with this Standard.
2. Arrange for independent safety and hazard reviews by appropriate personnel and committees.
3. Ensure that personnel assigned to design, construct, install, operate, and maintain equipment are trained, qualified where appropriate and are aware of this Standard.
4. Maintain necessary documentation for classroom training and on the job training.

C. ***The Environmental Safety and Health Coordinator**** is responsible for providing oversight and guidance on the guidelines in this Standard. The ES&H Coordinator shall:

1. Arrange for the review of all equipment installations and operations that may affect personnel safety.
2. Review those operations and maintenance precedures that may affect personnel safety for conformance with this Standard.

D. ***The Safety and Environmental Protection Division*** is responsible for:

1. Assisting Departments in reviewing electrical systems.
2. Assisting Departments in interpreting and implementing all applicable codes, standards, and regulations.

E. ***The Laboratory Electrical Safety Committee*** is responsible for:

1. Reviewing electrical equipment or installations that may have potential for severe injury to personnel, or severe impact on safety or operations, when requested by the Department.
2. Clarifying and guiding the Departments on the need for procedures for installing or operating equipment.

*This function may be carried out by other personnel.

IV. REQUIREMENTS

A. *Capacitors and Capacitor Banks*

1. *Description*

This section deals with capacitors and capacitor banks with stored energy in excess of 10 joules and voltage to ground exceeding 300 volts. It is particularly directed to the application of capacitors which are used as a source of pulsed power, for blocking and filtering, and in oscillator and resonant circuits.

2. *Hazards, Design, and Operating Criteria*

a. General

Capacitor banks shall be isolated by elevation, NEC barriers, or enclosures to preclude accidental contact with charged terminals, conductors, or support structures. Enclosures and barriers shall be used to protect personnel from projectiles that might be expelled from the capacitors during a fault: for capacitor banks capable of storing more than 50 kilojoules of energy, special enclosure requirements may be required to provide protection.

Oil filled capacitors should be avoided in Radiation environments. Experience has shown that the radiation breaks down the oil and causes a potential over pressure hazard.

Access to capacitor areas shall be restricted until all capacitors have been discharged, shorted, and grounded.

All capacitors in storage shall be short-circuited with a conductor securely fastened to the terminals and left in place until the capacitors are used again or scrapped.

Ventilation to keep the temperature of ambient air at capacitor installations at recommended levels shall be provided.

Capacitor cases, unless obviously connected to a recognized grounding conductor or grounded structure, shall be considered “charged”, and shall be grounded in the same manner as capacitor terminals. The capacitor cases should be properly labeled, with their operating voltages identified in accordance with OSHA Regulations.

b. Stored Energy

Capacitors or capacitor banks with stored energy of 10 joules or more constitute a LETHAL SHOCK HAZARD. Although they have been disconnected and discharged, capacitors may accumulate a charge without benefit of connection to an external power source. This charge is caused by the slow release of electric charges from within the dielectric material, because of the phenomenon known as “dielectric absorption”. It also is possible for capacitors to acquire a charge from local atmospheric electrical disturbances and by corona from a nearby high-voltage terminal, such as on an adjacent capacitor.

During transient conditions, capacitors could acquire a charge hazardous to personnel, or an overvoltage harmful to the capacitor itself because of inductance in the circuit. This inductance can be in the form of coils or magnets, or in wiring and leakage.

c. Discharging

Discharging a capacitor by a grounding hook can cause an electric arc at the point of contact. Such release of energy can also cause burns from thermal radiation or flying molten metal. Any residual charge shall be removed from capacitors by grounding the terminals with a low-impedance grounding hook before beginning to work with them. Automatic discharge and grounding devices shall not be relied upon for personnel safety; grounding hooks must be used to ensure safe operations. Grounding hooks shall be inspected periodically to ensure that all connections are secure, and that the grounding conductor is in good condition. Grounding the output typically will not discharge internal capacitor banks.

Short circuit all capacitors in storage with a conductor not smaller than #14 AWG, securely fastened to the terminals and left in place until the capacitors are used again.

d. **Connecting**

A dangerously high voltage can exist across the impedance of a few feet of grounding cable at the moment of contact with a charged capacitor. Operating personnel shall stand clear of cables attached to grounding hooks at the moment of application to a capacitor terminal.

e. **Safety Devices**

Safety devices, such as shorting switches and grounding switches, buswork, and their associated cables and cable connectors, shall be designed to withstand the mechanical forces from the large currents which result from their operation.

Protective devices, such as automatic shorting switches and grounding hooks, shall be tested after installation, and periodically thereafter to verify their operation.

f. **Faults**

Internal faults may rupture capacitor containers, particularly when many capacitors are connected in parallel. This rupture is normally caused by the boiling of the insulating liquid in the capacitor and may even occur where the peak fault current is not high. Metal case capacitors will usually swell and vent before large amounts of overpressure occur. Cast or phenolic cased units present a more serious hazard: the force of the explosion may cause serious injury.

Capacitors should be provided with current-limiting devices, such as fuses and resistors, which are capable of interrupting available fault current or limiting it to safe and manageable values. When this is not possible, alternate means to ensure personnel protection should be incorporated i.e. enclosure.

Rupture of a container by an internal fault can create a fire hazard because combustible dielectric could be ignited.

g. **PCBs**

Chlorinated dielectric fluids can release toxic gases when decomposed by fire or the heat of an electric arc.

All new installations with liquid filled capacitors shall be labelled from the vendor “No PCB’s".

Capacitor installations shall be monitored for leaking or deformed capacitor cases. A leak is defined as both intentional and unintentional spills, leaks, and other uncontrolled discharges where the results in any quantity of PCB’s running off on or about to run off the external surface of the equipment or other PCB source. Any leaks must be reported immediately to S&EP at 4207. When leaked oil is discovered it should be assumed to have PCBs unless proven otherwise. The unknown oil shall be analyzed for PCB concentration. Contact the S&EP Safety Representative to initiate the oil analysis and to arrange for its safe disposal through the Hazardous Waste Management Group (S&EP). All capacitors containing PCB shall be sent to this Group when their use is terminated.

h. **Fuses**

Fuses may be used to interrupt the discharge of energy from a power source or a capacitor bank into a faulted individual capacitor. If fuses and the capacitors are not adequate for this application, they could explode, expelling dangerous projectiles. Fuses designed for AC. operation depend on the current passing through zero on the next reversal of the line voltage to guarantee that the fuse will clear. Even if the correct D.C. rated fuses are used, a complete capacitor bank may discharge through a fault at very high currents before the fuse clears. The fuse in this type of application usually does not allow a shorted capacitor to permanently load a power source that is feeding it, such as in power-factor correcting service on power transmission lines.

i. **Bleeder Resistors**

It is essential that bleeder resistors be used on each capacitor that is fused to ensure that the capacitor discharges when it becomes isolated. If bleeder resistors are not used to discharge the capacitors, the capacitors must be automatically discharged (See National Electric Code (NEC) 460-6). The residual voltage on capacitors must be reduced to 50 V or less within one minute.

B. *Electrical Conductors and Connectors*

1. *Description*

The conductors and connectors covered in this section are those used in special R&D activities and include pulsed or continuous high-current, high-voltage, high-frequency, liquid-cooled, and other special conductor and connector applications.

2. *Hazards, Design, and Operating Criteria*

a. **Conductor overheating**

Dense packing of electrical cables in cable trays or raceways can cause overheating and insulation deterioration, leading to electrical arcing and fire. Conductor current capacities shall be derated commensurate with density of packing. Conductors shall also have capacity ratings sufficient for the capability of the energy supply system.

b. **Insulation**

Conductor insulation must be appropriate for the operating and environmental conditions. Insulation shall be selected based on thermal ratings, voltage ratings, mechanical strength, and resistance to moisture, chemical, and radiation environments. Cable exposed outdoors should be identified as being sunlight-resistant. Cable used in air-handling plenums must be specifically rated for this application. The general use of flame-retardant insulation/jacketing systems rated to pass the IEEE-383 vertical tray flame test shall be used where commercially available. Examples are XLP/Hypalon, EPR/ Hypalon, or a combined insulation/jacket of Hypalon for all cable.

c. **Shielded Cable**

Shielding confines the electric field of the inner conductor to the conductor insulation system. Insulated cables constructed with metallic sheath armor or with a discharge resistant jacket should be shielded if operated at or about 5 kV. For insulated cables constructed without armor or discharge resistant jacket, shielding should be used when operated at 2 kV or above.

d. **Physical installation**

High fault currents, or pulsed operation of cables, can produce large electromagnetic forces, resulting in physical movement of components. Bracing and conductor supports shall be provided that can physically and electrically withstand expected mechanical forces and voltages. Physical barriers shall be provided to separate high-voltage conductors from low-voltage conductors, and they shall be designed to withstand fault conditions. Spacing or loops between high-current supply and return conductors should be avoided to prevent inducing current in adjacent circuits or structural members. Suitable routing and additional protection shall be provided for coaxial cables used in pulsed-power applications, where the braid of the coaxial cable may have significant voltage with respect to nearby structures. Single conductors installed in cable tray shall be AWG l/O or larger.

e. **Metal Pipes**

Metal pipes that are used as electrical conductors present shock hazards because they may not be readily recognizable as electrical conductors. Accordingly, labeling, insulation, or other protection shall be provided for metal piping used as conductors.

f. **Liquid-Cooled Conductors**

Where liquid-cooled pipes or cables are used, sensing devices for coolant flow or overheating shall be provided for equipment shutdown if the cooling system malfunctions.

g. **Cable Care**

Cables and their insulation systems shall be physically protected. Walking or climbing on cable trays shall not be permitted. Individual or bundled cables shall not be run unprotected across floors for experimental work: suitable protection and suitable cables shall be provided where electrical systems must be run across floors. Cables used in recurring experimental activities shall be carefully handled and stored between uses.

h. **Terminations**

Improper selection, application, or installation of connectors can cause overheating, arcing, and shock hazards. Connectors shall have adequate current-carrying capacity and voltage rating for their application. Adequate separation shall be provided between adjacent high- and low-voltage cable terminations. Appropriate connectors shall be provided for use with aluminum conductors, and they shall be assembled in accordance with approved techniques. Connectors wired to sources of power should be female. Cable connectors shall be checked periodically and adjusted for tightness in accordance with normal maintenance procedures. Plug-in cable connectors, particularly those for high voltages or high currents, shall be mechanically fastened in place, and the power source shall be de-energized before inserting or removing these connectors. Cable splices are not permitted in conduit runs or where inaccessible, but may be used in cable trays provided they remain accessible and do not project outside the side rails. Cable splices must be adequately insulated.

i. **Wiring Methods:**

Unprotected flexible cords and cables are not permitted to be used as a substitute for fixed wiring. In accordance with the National Electrical Code, wires and cables must be physically protected by being run in cable tray, considered below, or in raceway, a general term denoting enclosed channels (rigid, thinwall and flexible conduit, wiring trough, etc.) designed expressly for holding wires, cables or busbars. Just as ac power systems are afforded superior protection by installation in raceway, safety-related or similar important systems should also be installed in raceway. Cables that share raceway or cable tray shall all have insulation ratings adequate for the voltage expected on any conductor in the raceway or cable tray.

Use of CABLE TRAY is limited: the National Electrical Code (Article 3 18) requires that only qualified persons may install and maintain cable tray systems. Cable trays shall be installed as complete systems, shall be exposed and accessible, and shall be electrically continuous and grounded. Single conductors installed in cable tray shall not be smaller than AWG l/O. Power and control cables supported by cable tray should be rated for use in cable tray. Power cables should be installed in cable trays separate from control, signal, and instrumentation cables. Listed fire stops should be provided when tray penetrates floors or other fire cutoffs. Wires may not be spliced where hidden in conduit, although splices are permitted in trough or in cable tray (splices may not project outside the tray rails). Note that screwed and bolted connections and poorly soldered lugs tend to loosen and overheat; crimped connections are more uniform in application and are recommended. Cable tray is generally provided to support cables: the integrity of cable tray systems should not be compromised by any items added to the cable tray cross-section, outside rails, or supports. Other restrictions apply to raceway or cable tray installations; appropriate knowledgeable professionals should be consulted when such installations are considered. They will consider the maximum allowable percentage of cable cross-section allowed to be filled with cable, the flammability rating and flame propagation characteristics of items within the tray, the cable tray support system and weight restrictions placed on the cable tray installation, and other items.

C. *Enclosures for Electrical Equipment*

1. Description

This section covers all enclosures for equipment in Hazard Ranges B, C, and D of ES&H Standard 1.5.0, and also includes equipment where rf radiation or stored energy electrical components are contained.

2. *Hazards, Design, and Operating Criteria*

a. **General**

All cabinets and enclosures shall be of appropriate materials and finish for the environment in which they will be placed. Enclosures structurally adequate for their intended use shall be provided. Adequate material shall be used in viewing windows to protect personnel from flying parts that may result from electrical faults. Enclosures shall be designed so that no contact with live electrical parts can be made from outside, and so that adequate interior working space is provided. Enclosures shall be grounded.

b. **Eddy Current, RF, or Microwave Heating**

Signs and/or warning lights shall be provided to indicate these hazards. Properly shielded enclosures shall be provided for rf power equipment, and particular attention shall be paid to all openings, such as doors, access ports, and viewing windows as inadequate shielding can result in burns. Compliance with ES&H Standard 2.3.2, “RF & Microwaves”, shall be provided by the use of proper equipment at the operating frequency to perform initial and routine measurements of radiation leakage: and taking special measurements after equipment modifications or changes in radiation levels.

c. **Interlocks**

Electrical interlocks shall be provided as appropriate on doors, easily removable panels, and swinging panels that interrupt the circuit wherever there is access. Door locks should limit access to authorized personnel only. When a temporary enclosure is necessary, it should be electrically interlocked, if possible, and should meet the same requirements as a permanent enclosure where hazardous conditions exist, before energizing equipment. Interlocks provide additional protection to systems and should be used as appropriate.

d. **Compartmentalization**

Separate high- and low-voltage and/or instrumentation and control compartments shall be provided in all enclosures, especially large, high power systems.

D. *Inductors, Electromagnets, and Coils*

I. Description

This section covers inductors, electromagnets, and coils with stored energy of more than 10 joules, which are used in in the following applications:

a. Energy storage systems.

b. Inductors used in a pulsed system with capacitors, to provide oscillatory waveshaping or resonant conditions.

c. Electromagnets and coils which produce magnetic fields to guide or confine charged particles.

d. Inductors used in dc power supplies.

2. *Hazards, Design, and Operating Criteria*

a. **Inductor Damage**

Overheating from overloads, insufficient cooling, or failure of the cooling system could cause damage to the inductor and possible rupture of the cooling system. Sensing devices (temperature, coolant-flow) shall be provided for water or air-cooled inductor and magnet coils, interlocked with the power source. These devices are for safe shutdown if temperatures are abnormally high or the cooling system fails.

b. **Fringe Fields**

Large electromagnets may produce external fields which can affect the calibration and operation of protective instrumentation and controls. Such external fields could also attract nearby loose magnetic material and cause injury or damage by impact or extreme forces. Where required, protective enclosures shall be fabricated from materials not adversely affected by external electromagnetic fields produced by the equipment. All personnel shall be advised of stray magnetic fields, by posted instructions. When they are in the vicinity of large magnetic fields, personnel should be trained of the dangers of having magnetic material in their clothing or on their bodies. Personnel with Bio-electronic implants should avoid exposure to electromagnetic fields. While there is no evidence of biological effects from magnetic fields, there is no proof to the contrary.

c. **Eddy Currents**

Whenever a magnet is suddenly de-energized, production of large eddy currents in adjacent conductive material can cause excessive heat. A fast rate-of-change of field strength produces high turn-to-turn and terminal voltage and also can induce voltages in adjacent conductors, which can be hazardous.

Equipment supports and bracing to withstand forces produced during normal operation and fault conditions shall be provided.

d. **Leads**

Loose and broken inductor or magnet connections can produce excessive heat and arcing. Extreme caution shall be exercised when disconnecting the leads of any large inductor. First, the power source should be locked out, as per ES&H Standard 1.5.1 “lock out/tag out” and then, when the current has decayed to zero, the leads can be disconnected.

e. Quench

Large amounts of energy stored in the field of an energized inductor can damage equipment and injure personnel if the energy is suddenly discharged in an inappropriate manner. A means shall be provided for safely dissipating stored energy when excitation is interrupted or when a fault occurs. The relatively long-time constants in large inductive circuits can cause the continuous release of energy into a fault, producing severe equipment damage and possible fire. An appropriate emergency off system shall be provided to dissipate stored energy and to disconnect it from the source. All terminals must be covered to protect from accident shorting.

f. **Grounding**

Electrical supply circuits and magnetic cores shall be grounded wherever feasible and fault protection shall be provided. Ground-fault detection shall be provided for grounded and ungrounded electrical circuits (floating systems), for alarm purposes or for equipment shutdown.

g. Warnings

Signs and/or warning lights shall be provided to indicate equipment hazards.

E. *Instrumentation and Control Systems*

1. *Description*

Instrumentation and control systems covered in this section are those used in special R&D.

2. Hazards, Design, and Operating Criteria

a. Process Isolation

Instrumentation and control (I&C) systems may be connected to circuits operating at hazardous voltage levels or with the capability of delivering high currents. Failure of insulating or isolating devices could extend such dangerous conditions to personnel, or could alter the I&C components in such a way that control of the process is lost, or information about the process is distorted. To prevent this from occurring, isolation must be provided for all such systems, between the I&C components and the process or equipment that is being monitored and controlled. Isolation shall include physical separation between power and signal circuitry and equipment, and the use of surge protectors and isolation devices such as transformers, high impedances, optical coupling, and telemetering. Both normal and fault conditions shall be considered during the design of such systems. Signal wiring shall not be bundled with power wiring. Consistent grounding methods shall be used in each facility for shields in instrumentation cables.

b. Hazardous Systems

Failure or malfunction of an I&C system can produce erroneous readings which can prevent recognition of hazardous conditions, can cause unintentional operation of hazardous equipment, or can inhibit the operation of safety devices such as enclosure interlocks, warning devices, or overload protection. Redundant controls and instrumentation shall be provided on sections of a system where a single failure could otherwise result in hazardous conditions or operation. Redundant instrumentation should monitor acutal conditions and provide independent verification of process conditions by monitoring required system attributes, i.e., flow derived from a flow monitor and not simply from operation of a solenoid valve. Control circuits shall be designed to be fail-safe, so that loss of power or a similar equipment failure does not result in a hazardous operating condition. A clear indication shall be provided of the status of hazardous remotely-controlled equipment, and each specific command shall be verified by definite feedback to the operator. Control circuits shall be designed to preclude the existence of “sneak” circuits (undesired circuits through series-parallel configurations), and shall be arranged so that accidental grounding of one conductor cannot cause safety devices to become inoperative.

c. Electrical Ratings

Electrical ratings of equipment and conductors shall be consistent with requirements of the National Electrical Code. Relay and interlock contacts on instrumentation and protective circuits shall be rated at least as high as the voltage of the circuit, and current ratings shall be as high as the normal disconnect rating of the protective fuse or circuit breaker used. Circuit inductance shall be considered in the application of relays and interlocks. BNL Hazard Class B, C, and D terminals in instrumentation and control compartments shall be covered and conspicuously labeled (ES&H Standard 1.50).

d. Computers/Programmable Controllers

Systems controlled by computers or programmable controllers shall be integrated to be fail-safe, so that failure of the stored-program device will result in a safe condition. The failure monitor shall be arranged in the form of a “heartbeat” circuit or equivilent, such that, a failure will not cause an unsafe condition in which must be continually refreshed by the computer/programmable controller. Manual overrides shall be provided so that a process connected to a computer or programmable controller can be interrupted by an operator regardless of the state of the stored-program device.

e. Manual Restart

Protective interlock circuits and process equipment controls shall be designed so that restoration of control or interlock circuits, or resetting of equipment that caused a process trip, will not automatically restart the process, without operator reset.

f. **Safety**

Immediate attention shall be given to malfunctions or failures of I&C systems adversely affecting safety, and corrective action should be taken in accordance with ES&H Standard 1.1 .O "Notification, Investigation and Reporting of Unusual Occurances". All new or modified instrumentation and control systems shall be carefully inspected and tested to assure that they perform in accordance with operating and safety requirements. Interlocks provided for personnel safety shall be tested and documented initially and at least annually to assure operability. Written checklists, including simulation of failures, operation of upper- or lower-limit control features, safety interlocks, and interlock systems should be incorporated into the procedures. Safety interlocks shall not be used in leiu of lockout/tagout equipment and procedures required by ES&H Standard 1.5.1.

g. **Graphic Display Panels**

Graphic control displays should be provided for large or complex systems. Consistent labeling types and nomenclature shall be used for control panels.

F. ***Power Supplies***

1. ***Description***

This section covers power supplies that are used in R&D activities, and are within the ranges of Table 1 in ES&H Standard 1.5.0 for Ranges B, C, and D. The power source can be either AC or DC, and from a protection point of view, the circuit extends to the connected load.

2. ***Hazards, Design, and Operating Criteria***

a. **General**

Before initial operation and at 1.east annually thereafter, the power supply shall be carefully inspected, calibrated, and the inspection documented, and all protective devices shall be checked.

b. **Covers**

Personnel could unknowingly come in contact with energized equipment. All terminal strips and live components shall be covered or protected by barriers; where visibility of the components is necessary (e.g. relays, contactors), the covers shall be made of transparent material. To the extent possible, access to incoming power to a power supply shall be limited, preferably through use of a separate compartment, or barriers.

c. Power Sources

Multiple input sources shall be avoided. A power supply in a remote location could be energized and personnel could unknowingly come into contact with the energized equipment (connected load). Where other sources are connected to a power supply, either externally or coupled into the power supply from the load itself, the power supply shall be clearly labelled with the source name and its location. Equipment shall be labeled to identify input power sources, which shall be labeled to identify their connected power-supply loads. Induced or back emf sources shall also be identified. Equipment which is remotely controlled or unattended while energized shall be labeled with emergency shutdown instructions, and the identity of the personnel who are responsible for the equipment shall be on the power supply, or prominently displayed in the building or area location.

When power supp ies serve more than one load, switching errors can result in energizing the wrong equipment (Ioad), creating hazards to nearby personnel.

d. **Faults**

Electrical faults or switching transients can cause voltage surges in excess of the normal terminal voltage rating of the power supply. Electrical faults can cause conductors to melt, and other components such as insulating materials could melt, burn, or explode. Protection from AC and DC instantaneous and continuous overcurrent, overheating, shall be provided, as applicable. Load protection and ground protection shall be coordinated with the above, including cables (insulation, rating, and size).

e. **Wiring**

Power supply power, control wiring, and load cable insulation shall be high temperature rated (105°C) wherever possible, shall be selected for low oxygen content, and shall have passed IEEE or UL flame tests. Refer to paragraph IV B, "Electrical Conductors and Connectors".

f. **Component Failure/Overload**

Overload or improper cooling can cause excessive rise in temperature, resulting in possible damage to equipment and associated hazards. Internal component failure can cause excessive voltages on external metering circuits and low-voltage rated components of the power supply. Provide overcurrent, undervoltage, or other protection for both power supply and load as appropriate.

g. **Shutdown**

The design of the power supply shall include a positive means of interlocking (preferably mechanically) its cabinet so that accidental access to energized components is prevented. The main input circuit breaker or disconnect switch shall be clearly identified, located as near as possible to the power supply, and equipped with lockout provisions coordinated with interlocks of the power supply. Control power should be generally derived from the AC input power so the disconnect deenergizes both. In addition, a second means of shutdown shall be installed at the power supply, when the power supply is not in sight of the main disconnect device. Before entering power-supply or associated equipment enclosures the following precautions shall be taken:

(1) Open and lockout the main input power circuit breaker and verify that the input voltage is off. (ES&H Standard 1.5.1 "Lockout and Tagout").

(2) Check for auxiliary power circuits which could still be energized.

(3) Inspect automatic shorting devices if installed, to verify proper operation.

(4) Short power supply from each terminal-to-ground and terminal-to-terminal, with grounding hooks.

An automatic switch or a bleeder resistor shall be provided in the power supply to discharge all stored energy when the power supply is turned off. This feature shall be interlocked with the other power supply safety systems, especially where large capacitive filters or capacitor banks are used. The residual voltage on capacitors must be reduced to 50 V or less within one minute.

In the control systems of the power supply, remote/local mode switches are desirable. Remote shutdown or means for emergency stop shall also be provided.

h. **Discharge**

Output circuits and components can remain energized while input power is interrupted, because of parallel power sources or stored energy in reactive components (e.g., capacitors). For inductive loads, discharge paths for the stored energy, including, but not limited to, thyrites, MOV's, and reverse connected diodes, shall be provided.

i. **Indicators**

Auxiliary and control power circuits can remain energized when the main power circuit is interrupted. Alarms, signs, or lamps shall be provided to indicate that a power supply is energized. If the local switch is remote from the power supply, there should also be a lamp to indicate a load.

G. *Resistors and Resistor Banks*

1. *Description*

Resistors and resistor banks used in R&D are typically used to connect instruments to a high-voltage circuit (as in a voltage divider and filter damping resisters), and to absorb the discharge of stored energy, where they may carry pulsed current exceeding their steady-state rating. Resistors and resistor banks may also be used in safety-related functions, such as resistive grounding.

2. *Hazards, Design, and Operating Criteria*

a. **Resistor Ratings**

Each resistor should be operated within its rating or capability. Large currents from faults or abnormal circuit operation may produce forces capable of destroying resistors. Resistors used where large pulse or fault currents may be expected shall be robust enough to withstand the resulting magnetic forces.

b. **Physical Installation**

Improperly installed resistors may injure personnel or damage adjacent equipment, because resistors may operate at temperatures high enough to cause severe burns or to ignite combustible materials. They may also be used in applications involving high voltages or currents. Resistors used in hazardous applications should be installed in an enclosure to prevent injury and minimize damage if a failure should occur. The enclosure should be well-ventilated, constructed of non-combustible material, grounded, and interlocked to prevent entry while the resistors are energized. Signs should be posted to warn personnel of the hazards present in resistor installations; warning lights and barriers may also be required.

Resistors should be installed in a manner to preclude damage to adjacent components from heat. The insulation of conductors used to connect resistors should be able to withstand the temperatures and voltages encountered. Resistors used in high-voltage circuits should be protected from surface contamination caused by adverse environmental conditions.

c. **Transient Conditions**

Resistors should be capable of withstanding any transient overvoltage to which they may be subjected. Resistors used in pulsed circuits or discharge circuits can be physically damaged when operated at high-current or high-voltage levels, or when subjected to overvoltages, which might cause electrical arcs. Resistors applied in pulsed circuits should be sized to accommodate any possible succession of pulses. Resistors in grounding circuits may develop hazardous voltages during the flow of fault or discharge currents.

d. **Hazards Introduced by Resistor Failures**

When failure of a resistor could expose personnel to hazardous voltages, the installation of two or more resistors in parallel should be considered, each rated for maximum operating conditions. For example, failure of a resistor used in the low-voltage section of a voltage divider will result in applying the high voltage to the divider output terminal. Also, failure of a capacitor bleeder resistor could expose personnel to hazardous voltages.

Failure of an inductor discharge resistor, such as that used for a motor field winding, can result in hazardous and destructive voltages in the motor circuit. Failure of a resistor used as a discharge device for an energy storage system may create a hazardous condition when the discharge circuit does not function as intended.

e. **Water-cooled and Forced-Air Cooled Resistors**

Temperature-sensing or flow-sensing devices should be installed in resistor installations which require liquid cooling or air cooling. Water-cooled resistors may explode if insufficiently cooled; electrolytic resistors may simply open if the fluid level gets low. Resistors can operate at temperatures that are high enough to cause burns to personnel or ignite combustible material.

f. **Inspections**

The resistor installations including enclosure interlocks should be inspected periodically.

H. *Electrical Switches*

1. *Description*

This section covers special non signal electrical switches used in R&D where safety requirements are not specifically covered by existing codes.

2. Hazards, Design, and Operating Criteria

a. **Electrical Shock**

Electrical shock from contact with live exposed switch parts is a common hazard. Lockable and grounded switch enclosures shall control access to the switches. Protective covers and/or barriers shall be provided when practical to prevent personnel from coming in contact with live parts.

b. **Location**

Switches shall be located as close as practible to equipment they are servicing (within line of sight). Switches shall be labeled as to where they are fed from. Switches, contactors and relays shall be mounted so that gravity tends to open the contacts or switch blades with loss of power or poor mechanical connection.

c. Phase Arrangement

Both line and load conductors shall be phased A-B-C from left to right on all three-phase switches, circuit breakers and contactors.

d. **Operation**

There must be assurance that switches not designed to disconnect under load conditions cannot be opened when the circuit is energized. Switches not intended to be opened under load conditions can create severe arcing.

e. Maintenance

A system of interlocks which interrupts the normal operating control power to remotely-controlled switches during testing or maintenance shall be provided. Locking features on switches to prevent operation when personnel are working shall accommodate the requirements of ES&H Standard 1.5.1 "Lockout/Tagout".

Periodic (at least annual) inspections of switch conditions and switch operating tests shall be performed and documented, for criticalo r high value equipment.

f. **Fault Conditions**

Sufficient energy may be developed under fault conditions to cause a switch to explode. Arcing at switch terminals under transient fault conditions can subject the isolated section of a circuit to hazardous voltages and power levels. Switches used above their voltage and current ratings can cause shocks or other electrical hazards. Switches shall be selected so that under fully loaded and fault conditions their voltage, current, and interrupting ratings are not exceeded.

g. **Unintentional Operation**

Electrically controlled switches operated unintentionally, because of malfunction of the control circuits, present a shock hazard. All switches shall have a positive indication of switch position and function; unlabelled or improperly labelled switches also present a shock hazard. Operating procedures for checking that no one is working on the load and that all protective grounds have been removed before restoring power shall be established and implemented.

h. **Switch Locking**

Suitable means shall be provided for locking secondary isolating and/or transfer-type switches in the desired position. Wherever possible, however, disconnect switches should not be locked in the ON position, preventing circuits from being readily de-energized.

I. ***Storage Batteries and Battery Banks***

1. ***Description***

This section covers rechargeable-type batteries used for storage of electrical energy. These criteria are not limited to batteries of a particular voltage and energy rating, because the nature of the associated electrical hazards is similar for any battery size, except that the severity of the hazard increases with increased battery rating. This sectionis not intended to cover small batteries, i.e., watches, calculators, computer backup or hearing aids.

2. ***Hazards, Design, and Operation Criteria***

a. **General**

All storage battery installations, including handling and storage areas, require special attention to ensure that batteries have a safe operating and storage environment.

b. **Access**

Access to station storage battery areas should be limited to authorized personnel only, through the use of locked doors and/or locked gate enclosures. Warning signs shall be posted prohibiting smoking.

c. **Location**

Batteries shall be located in a dedicated clean, dry room where there is sufficient ventilation to prevent an accumulation of explosive mixture of gases from the batteries. Unrestricted natural air movement in the vicinity of the batteries, together with normal air changes for occupied spaces or heat removal, may be sufficient. Mechanical ventilation in the vicinity of the batteries will be required for confined spaces. Ventilation can consist of a fan, roof ridge vent, louvered areas, or combinations of these. The ventilation system must be Class I Division I, as per NEC 500 and approved by S&EP.

d. **Vapors**

The vapors given off by storage batteries are very corrosive; therefore, wiring and its insulation is required to be of a type that will withstand corrosive action. Metal battery racks and metal raceways shall be constructed of treated material to make them resistant to corrosion.

The floor of storage battery areas should be of an acid-resistive material, or be painted with acid-resistive paint, or otherwise protected.

e. Physical Installation

Choice of battery type, charging circuitry, and construction of storage area shall be consistent with the intended application of the installation. Protection devices installed shall be as required by applicable codes and/or specified by manufacturer of packaged battery/charger system. Large battery banks for UPS service should have fused disconnects installed as per NEC article 480.

Battery racks shall be firmly anchored to either the floor or to the wall. Metal battery racks shall be grounded. DC Systems between 50 and 300 volts should be grounded, including battery systems (refer to National Electric Code article 250-3).

f. **Maintenance**

Procedures for regularly scheduled maintenance, testing, and inspection shall be developed and implemented. These procedures should include testing and recording voltages and specific gravity of batteries, and the routine cleaning and torquing of connections. Maintenance, testing, and inspection of package battery/charging systems should follow the manufacturers recommendations.

g. Spills

Provisions for neutralizing acid spills (bicarbonate of soda and water solution) should be provided. Equipment shall be provided to prevent spills from entering the facilities drainage systems, i.e, secondary containment.

h. **Personnel Protection Equipment**

Personal protective equipment for personnel working in the battery areas are goggles and face shields, acid resistant gloves, and protective aprons. An eye wash station and an emergency shower in close proximity to the storage area shall be installed, and shall be easily accessible.

J. ***Chemical, Biological, Fire, and Other Hazards Associated with Electrical Equipment***

1. ***Description***

Electrical apparatus may contain hazards, which, while not electrical in nature, are intimately associated with the equipment. These hazards may involve physiological effects, toxicity, fire, explosion, corrosives, failure of safety systems from non-electrical causes, and many others. This section is not intended to present a detailed description of the hazards, with a full set of design and operation criteria for each. Rather, it is a list of some of the more probable dangers which may be encountered and which need to be considered while working with electrical equipment.

For most of the items listed, detailed codes, references, and standards exist. These explain the safety aspects of each area in great detail and may be consulted for more information.

This list can never be complete since new equipment, materials, applications, and designs continue to provide further sources of unusual and hazardous situations. In many cases, the electrical hazards associated with equipment (for example, batteries) are discussed in this Standard, paragraph IV I. Only the non-electrical aspects are included in this section.

2. ***Hazards, Design, and Opeating Criteria***

a. **General**

Warning signs shall be displayed indicating the presence of any potential hazard such as gas, fumes, laser light, UV, noise, toxic chemicals, nuclear radiation, fire hazards, magnetic fields, electromagnetic radiation, hydrogen, or other explosive gases. Operating permits flashing lights and audible alarms may be necessary in some cases. Warning signs should conform to OSHA guidelines.

Provide sufficient access and illumination around electrical equipment.

Areas where any toxic fumes may be present should be adequately ventilated. Permits may be required for air emissions (See S&EP).

Grounded protective covers or barriers shall be provided for high voltage terminals and for low voltage terminals that have high currents available, to prevent personnel or hand-held electric-conducting material from contacting energized parts.

Eye wash and safety showers near battery banks or other acid-containing equipment shall be provided, maintained, and kept assessable.

Protective devices, equipment, and/or systems shall be designed to be FAIL-SAFE, wherever practical.

Intercoms and telephone should be near hazardous equipment for use in emergencies. Their locations should be reported to Fire/Rescue and be properly posted, well-marked so that proper instructions can be given to responding emergency personnel.

A distinctive orange color-code and/or label shall identify any component which in its common use is nonhazardous, but in its actual use may be hazardous (e.g., a metallic cooling-water pipe also used as an electrical conductor, carrying high voltage or high current).

Warning or pilot lights shall be installed on the equipment and clearly indicate when equipment is energized.

b. **Grounding**

Metal cabinets, enclosures, and structural components and equipment shall be grounded with easily recognizable external grounding conductors sized for the maximum available fault currents.

Safety grounding hooks for hazardous electrical equipment for R&D shall have the following features:

(1) A visible, extra-flexible copper conductor of adequate size.

(2) Connectors crimped and/or soldered, and

(3) A bare conductor clearly visible through its insulating sheath.

(4) A bolted on connection from the conductor to the building ground. Spring type connectors should be avoided.

Grounding hooks shall have a clearly visible metal-to-metal bolted connection to equipment ground, shall be of sufficient number to satisfy the equipment grounding requirements, and shall be located in a visible and accessible location.

Where it is necessary for safety in equipment grounding, a discharge point should be provided, with an impedance capable of limiting the current to 50 amperes or less. A direct grounding point shall also be provided and the discharge and grounding point shall be clearly labelled.

c. **Specific Hazards**

Ozone – Many electrical devices generate significant quantities of ozone from sparking, corona, or ultraviolet light. Ozone, in concentrations as low as 0.1 ppm, can result in observable physiological effects. In areas where ozone may be produced, ventilation shall be provided (contact S&EP for measurement).

Hydrogen – Hydrogen is used often in R&D for accelerator targets and cryogenic magnets and is also a by-product of battery charging or other electrolytic type of operations. It is a highly flammable, highly explosive gas with a lower explosive limit of about 4% in air. There are usually pieces of electrical equipment used in conjunction with the hydrogen device, and any one of these may act as an ignition source during a hydrogen release. All sources of ignition should be removed from the area or explosion proof equipment used as per National Electric Code Article 500. (See ES&H Standards 4.12.0, “Special Precautions for Locations Containing Flammable Atmospheres” and 5.2.0 “Flammable Cryogenic Liquids”.) All Hydrogen use must be reviewed by S&EP.

Superconducting Devices – The increasing use of superconducting magnets and other devices presents several different hazards. If hydrogen is the cryogenic fluid, it is a potential fire and explosion hazard. Cryogenic temperatures may cause severe “burns”. When a cryogenic magnet “quenches”, it may cause a sudden pressure buildup as the liquid turns to gas. This pressure buildup can rupture the containment vessel and create an explosion-type hazard. (See ES&H Standard 5.1.0 “Nonflammable Cryogenic Liquids, and 5.2.0 “Flammable Cryogenic Liquids).

Chlorinated Oils (PCBs) – Oils, with trade names such as Chlorinal, Arochlor, Inerteen and Askarel, which have been modified to be fire-resistant, present a problem to both personnel and equipment and should not be used. These oils are toxic when ingested or absorbed through the skin. The presence of water in the oil causes hydrochloric acid formation which may damage equipment. When decomposed by heat, these oils release toxic gases such as phosgene. These oils are also a threat to the environment if spilled. All PCB-containing equipment must be labelled as such.

Batteries – In addition to the electrical hazards associated with high current storage batteries, there are other problems. The most commonly used batteries have a sulfuric acid electrolyte which requires careful handling. During charging, hydrogen is generated in the cells and an inadvertent spark can cause the battery to explode. Other toxic gases may also be generated (See section I, “Batteries”).

Noise – Continued exposure to very high noise levels such as may be present in the vicinity of some electrical equipment causes hearing to deteriorate. Sudden loud noises, such as a spark gap firing or capacitor bank discharging, can create a safety hazard by startling individuals who might be working on hazardous equipment such as machine tools or electrical equipment. (See ES&H Standard 2.4.0 "Noise")

Coolants – The coolants used in electrical equipment are most commonly water, oil, and anti-freeze, such as solutions of ethylene glycol. Release of the coolant near energized components can be a hazard. Water may create a leakage path for voltage, initiate short circuits, interfere with interlock systems, and create very good ground paths. Oil and glycol, when released, may cause slipping, which can result in physical injury as well as accidental electrical shock, and could become an environmental issue. Appropriate floor drainage shall be provided wherever electrical equipment is located, to minimize electrical shock hazards from accumulated moisture.

Environmental Effects – Any device which is used as part of a safety system is subject to malfunction as a result of environmental conditions. A relay may fail to release in the presence of a large stray magnetic field. Dirt or dust may make a contact inoperative and such failures may make a safety system inoperative. The environmental factors which have to be considered include temperature, dirt and dust, moisture, ice, dc magnetic fields, and electromagnetic fields.

Fire Hazards – Many of the materials used to construct electrical equipment are flammable. Inherent ignition sources are present in most electrical equipment and a fire is always a potential danger. Wire-insulating materials and capacitor oils that are commonly used can generate large amounts of smoke with toxic fumes arising from the chlorine, which is used in many insulating materials.

Thermal Sources – Electrical equipment may contain devices operating at temperatures which can cause thermal burns or initiate fires.

Moving Mechanical Devices – Unprotected actuators, fans, blowers, gears, and pulleys present a safety hazard. Guarding should be in conformance with OSHA. Automatic starting equipment also poses a hazard, and shall be labelled as such.

Light Sources – Lasers, ultraviolet and infrared light sources, spark gaps, and other devices can constitute severe eye hazards. The ultraviolet light can cause conjunctivitis, which may lead to permanent eye damage during very short exposures. Laser beams can cause retinal damage and severe burns to exposed body areas. (See ES&H Standard 2.3.1 "Lasers")

Magnetic Fields – There is concern that there may be effects to biological organisms from exposure to dc magnetic fields. Unwarranted, long-term exposures, such as near bubble chambers, should be minimized. Carrying magnetic tools or equipment near magnets with large stray fields can lead to physical injuries. (See ES&H Standard 2.3.3 "RF and Microwave".)

Electromagnetic Radiation – High-power pulses electromagnetic radiation can cause secondary effects near the source, such as sparking between any conducting materials in the area, heating of nearby objects, and biological effects such as tissue burning. (See ES&H Standard 2.3.3 "RF and Microwave")

Bio-electronic Implants – Many people have implants, such as pacemakers, which may be sensitive to electromagnetic fields. Exposure to electromagnetic fields should be avoided.

X-rays – Many high voltage devices (greater than 10 kV) in vacuum such as klystrons, high voltage rectifiers, and high voltage tubes generate x-rays as an unwanted by-product. Proper attention to personnel protection shall be considered. Shielding for x-ray sources as well as high voltage devices producing x-rays as a by-product shall be provided. (See ES&H Standard 3.4.2 "Analytical X-Ray Facilities")

Nuclear Radiation – Electrical and electronic equipment, which has been subjected to nuclear radiation may become activated and present a radiation exposure hazard to personnel.

Stored Energy Equipment – In addition to the electrical hazard, energy storage devices are capable of creating severe arcs and fireballs involving the vaporization and scattering of copper, steel, or other materials in the arc vicinity. Severe skin, and eyes can result from such an arc. An exploding capacitor can project busing and other material a considerable distance. In structural failures strong magnetic forces in coil and magnets can in some cases, produce hazards.

V. REFERENCES

A. DOE/EV-005 l/l “Electrical Safety Criteria for Research and Development Activities”.

B. NFPA 70 National Electrical Code.

C. NFPA 70 B Electrical Equipment Maintenance.

D. NFPA 70 E Electrical Safety Requirements for Employee Workplaces.

E. OSHA 19 10 Subpart S. Electrical.

F. ANSI 235.1 Specification for Industrial Accidnt Prevention Signs.

G. Environment Safety and Health Standard 1.5.0 “Electrical Safety”.

H. Environment Safety and Health Standard 1.5.1 "Lockout/Tagout".